CLAIMS

1. A method for controlling the temperature of a mass cooled by a free piston cryocooler, the method comprising:

(a) for output cooling power demands requiring a piston stroke exceeding a selected minimum piston stroke, controlling the output cooling power of the cryocooler by modulating piston stroke as an increasing function of the difference between sensed mass temperature and a command reference input temperature; and

(b) for output cooling power demands requiring a piston stroke less than the selected minimum piston stroke, maintaining the minimum piston stroke and applying thermal energy to the mass.

2. A method in accordance with claim 1, wherein the selected minimum piston stroke is the minimum piston stroke necessary to maintain gas bearing lubrication of the cryocooler.

3. A method in accordance with claim 2, wherein, for output cooling power demands requiring a piston stroke less than the selected minimum piston stroke, the thermal energy is applied as an increasing function of the difference between the cooling power applied to the mass by the cryocooler at the selected minimum piston stroke and the cooling power demand.

4. A method in accordance with claim 3, wherein, for nominal design operation, the output cooling power demand is greater than the output cooling power at the selected minimum piston stroke and is nearer the output cooling power at the selected minimum piston stroke than it is to the cooling power at a maximum permissible piston stroke.

5. A method for controlling the temperature of a mass cooled by a free piston cryocooler, the cryocooler having a piston and a closed loop control system, the control system deriving a piston drive signal from the difference between a set point signal and a fed back temperature signal representing the temperature of the mass, the method comprising:

(a) for piston drive signals corresponding to piston strokes exceeding a selected minimum piston stroke, controlling the output cooling power of the cryocooler by the piston drive signal;

(b) for piston drive signals corresponding to piston strokes less than the minimum piston stroke, maintaining the minimum piston stroke; and

(c) for piston drive signals corresponding to piston strokes less than the minimum piston stroke, applying thermal energy to the mass as an increasing function of the difference between the piston drive signal for the minimum piston stroke and the applied piston drive signal.

6. A method in accordance with claim 5, wherein the selected minimum piston stroke is at the piston stroke necessary to maintain gas bearing lubrication of the cryocooler.

7. An improved, temperature controlled, free piston cryocooler including a free piston driven in reciprocation by a prime mover having a modulatable stroke, the cryocooler including a cold end and a warm end and being capable of transporting heat away from a thermal load positioned at the cold end, the cryocooler having a feedback control system including (i) a temperature command input for inputting a reference signal representing a desired cold end temperature of the thermal load, (ii) a feedback loop including a temperature sensor at the cold end for generating a signal representing actual cold end temperature, and (iii) a summing junction for generating an actuating signal representing the difference between the desired temperature and the actual temperature of the cold end, the improvement comprising the combination of:

(a) a piston stroke modulator connected to receive the actuating signal and for converting the actuating signal to a piston drive signal representing a desired piston stroke, the modulator connected to the prime mover for controlling its stroke when the desired piston stroke exceeds a selected minimum stroke and maintaining the minimum stroke when the desired stroke is less than the minimum stroke; and

(b) a heating apparatus including a heater in thermal connection to the cold end and a heater control element having an input connected to receive the piston drive signal

for modulating the heater power as an increasing function of the difference between the desired piston stroke and the minimum piston stroke when the desired piston stroke is less than the minimum piston stroke.

8. An improved closed loop control system for controlling a free piston cryocooler having a heat pump including a piston, the control system controlling the temperature of a mass being cooled by the cryocooler and including (i) a dynamic leg, (ii) a reference input for inputting a desired, set point temperature and (iii) a feedback leg including a temperature sensor in thermally conductive connection to the mass being cooled, for comparison of a signal from the temperature sensor to the reference input to provide an actuating signal, the improvement comprising:

(a) a first branch of the dynamic leg comprising:

(i) a first controlled element including the prime mover and the heat pump and controlling the piston amplitude of oscillation; and

(ii) a first control element having an output connected to an input of the first controlled element and an input to which the actuating signal is applied for controlling the piston amplitude of oscillation, the first control element including an actuating signal limiter for maintaining the output of the first control element greater than a selected piston limit value substantially corresponding to a minimum piston stroke; and

(b) a second, parallel branch of the dynamic leg comprising:

(i) a second controlled element including a heater in thermally conductive connection to the mass; and

(ii) a second control element having an output connected to an input of the second controlled element and an input to which an actuating signal is applied for controlling the heating power output of the heater, the second control element, for an actuating signal value exceeding the selected piston limit value, applying substantially no heating power and, for an actuating signal value less than the selected piston limit value, applying increasing heating power as a function of decreasing actuating signal value.

9. A control system in accordance with claim 8 wherein the control elements comprise a digital microprocessor and associated storage forming a programmed computer system having control instructions and algorithms stored in the storage.